Learn Chemistry

Problem Based Practical Activities

Problem 9: Cool drinking

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This resource was produced as part of the National HE STEM Programme

National HE STEM Programme

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Problem 9:
Cool drinking

Curriculum links;
enthalpy changes, Born-Haber cycles

Practical skills;
experimental design, Health and Safety

The students are set the problem of designing a new drinks container which will cool 100 cm^3 of a drink by 5 °C in 5 min. The students need to decide which of ammonium nitrate and ammonium chloride should be used based on the enthalpy of solution, the solubility's in water, the cost and the relevant health and safety information for each salt. They then need to trial their method and modify the quantity of salt required accordingly.

Problem 9: Cool Drinking

Pre-Lab questions

(Remember to give full references for any information beyond A-level that you find out)

1. Give definitions for each of the following enthalpy changes. In each case include an equation to represent the process to which the enthalpy change applies;

a) Enthalpy of solution of the ionic compound X^+Y^-

b) Lattice energy of the ionic compound X^+Y^-

c) Enthalpy of hydration of the gaseous ion Z^+ (g)

2. The enthalpy of solution of an ionic compound can be calculated from its lattice enthalpy and the enthalpies of hydration of the individual ions. Use the enthalpy changes shown and a Born-Haber type cycle to calculate;

a) The enthalpy of solution of ammonium chloride, NH_4Cl (s)

b) The enthalpy of solution of ammonium nitrate, NH_4NO_3 (s)

	Enthalpy change / kJ mol^{-1}
Lattice energy of NH_4Cl (s)	–705
Lattice energy of NH_4NO_3 (s)	–646
Enthalpy of hydration NH_4^+ (g)	–307
Enthalpy of hydration Cl^- (g)	–381
Enthalpy of hydration NO_3^- (g)	–314

3.* In 2001, Nescafe launched a self-heating can of coffee. To heat up the coffee a button is pressed which mixes the heating ingredients; a single step mixes calcium oxide and water to produce calcium hydroxide and generate heat;

$$CaO + H_2O \rightarrow Ca(OH)_2 \quad \Delta H\ –82\ kJmol^{-1}$$

The can warms up 210 cm^3 of coffee by 40 °C.

a) Assuming that the heat capacity for coffee is the same as that of water (4.18 JK^{-1}g^{-1}) calculate the energy needed to warm 210 cm^3 of coffee by 40 °C.

b) Use this value to hence calculate the minimum mass of CaO needed in the can for it to function as specified.

***Question taken from 2003 International Chemistry Olympiad Booklet 2003 – Round 1**

Problem 9: Cool Drinking

Introduction

Bettie's Beverages
Milton Keynes, England

Dear Scientist,

Congratulations! You and your group have been selected for the contract job of designing my company's latest product. We are working to a tight schedule so your product must be finished A.S.A.P.

The product is a drinks can that, when desired, can be activated to cool the drink it contains wherever the user may be at the time. In the first instance we are looking for a product that can cool 100 cm^3 of drinkable water by 5 °C in no more than 5 minutes. Try not to exceed this temperature change as we do not want our customers' teeth to freeze!

You and your team will need to use your knowledge of chemistry to come up with a product design which includes full details of the cooling process with exact quantities of any chemicals used and time periods required to give us our desired –5 °C temperature change. We would like you to provide us with both theoretical and experimental quantities for any chemicals used in order for us to evaluate the effectiveness of your design. In order to pass the strict requirements of the Food Standards Agency it is also imperative that the cooling process is safe. We at the department have done a little research ourselves and have found two chemicals that we think would be useful;

ammonium chloride (NH_4Cl); solubility 37.2 g / 100 g water, £2.55 per 500 g

ammonium nitrate (NH_4NO_3); solubility 192 g / 100 g water, £10.95 per 500 g

Please include with your final product design an explanation of which chemical you decided most suitable and why, including careful consideration of the Health and Safety implications of your chosen design.

Finally we need to know that you have successfully tested your design. Please provide data to indicate this.

Thank you for accepting this contract and we look forward to seeing your results.

George Marshall
Product Development Manager

1. a) *Enthalpy of solution of the ionic compound X^+Y^-*

The heat energy change at constant pressure when one mole of X^+Y^- dissolves completely in water;

$$X^+Y^-(s) \ + \ water \ \rightarrow \ X^+(aq) \ + \ Y^-(aq)$$

b) *Lattice energy of the ionic compound X^+Y^-*

The enthalpy change when one mole of X^+Y^- is formed from its gaseous ions;

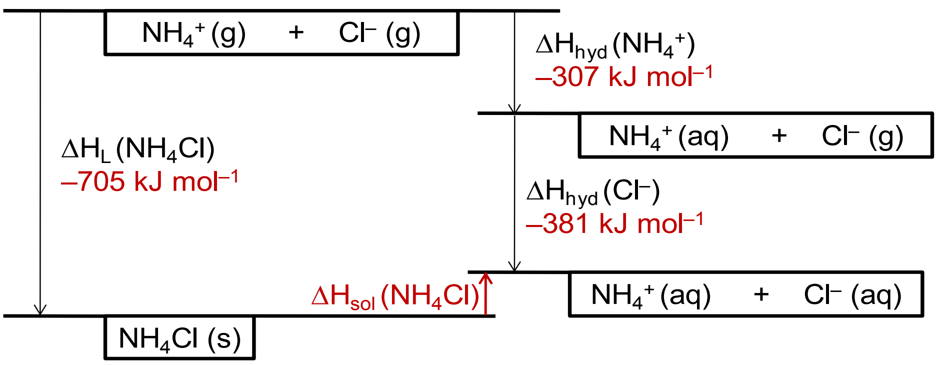
$$X^+(g) \ + \ Y^-(g) \ \rightarrow \ X^+Y^-(s)$$

c) *Enthalpy of hydration of the gaseous ion Z^+ (g)*

The enthalpy change when one mole of isolated gaseous ions, Z^+ is dissolved in water to form one mole of aqueous ions under standard conditions;

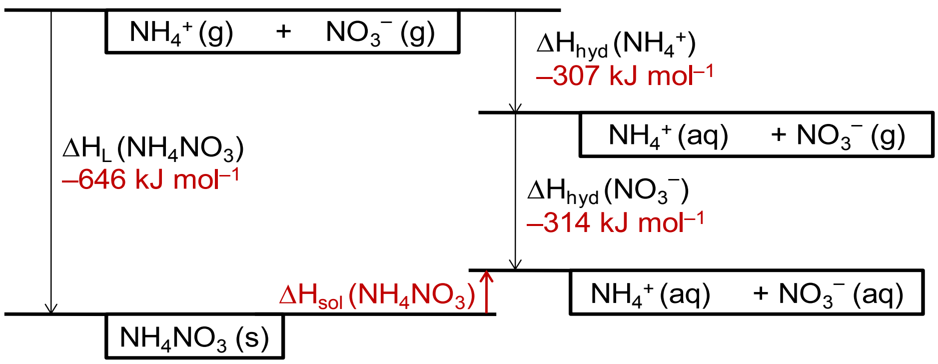
$$Z^+(g) \ \rightarrow \ Z^+(aq)$$

2. a) The enthalpy of solution of ammonium chloride, NH_4Cl (s);



$\Delta H_{sol}(NH_4Cl)$ = – –705 + –307 + –381 = **+17 kJ mol^{-1}**

b) The lattice energy of ammonium nitrate, NH_4NO_3(s);



$\Delta H_{sol}(NH_4NO_3)$ = – –646 + –307 + –314 = **+25 kJ mol^{-1}**

3. a) $Q = mC\Delta T$ $m = 210$ g (density of water = 1 g cm^{-3})

$C = 4.18$ J K^{-1} g^{-1}

$T = 40$ °C or 40 K

Hence $Q = 210$ g × 4.18 J K^{-1} g^{-1} × 40 K = **35112 J or 35.1 kJ**

b) $CaO + H_2O \rightarrow Ca(OH)_2$ ΔH –82 kJ mol^{-1}

Therefore reacting one mole of CaO produces 82 kJ of energy

So the no. of moles of CaO we need to react to heat the can = 35.1 kJ ÷ 82 kJ mol^{-1} = 0.43 moles

Mass of 0.43 moles of CaO (molar mass, 56.1 g mol^{-1}) = 0.43 moles × 56.1 g mol^{-1} = **24.0 g**

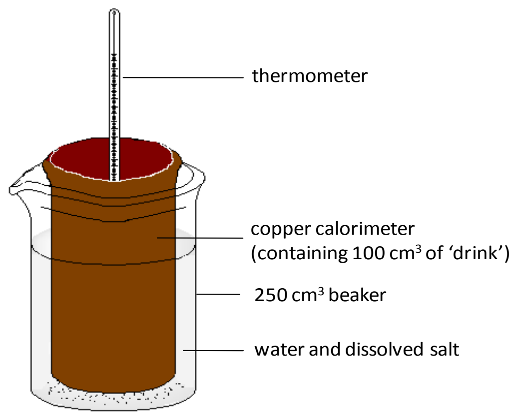
Teacher and Technician Pack

Proposed method

NH_4Cl is **harmful** if swallowed and irritating to eyes

Using the pre-lab questions, the students identify the dissolution of either NH_4Cl or NH_4NO_3 in water as endothermic reactions and therefore suitable methods for cooling the drink.

Following research into the H&S implications of using NH_4NO_3 **[Oxidising]** and its high cost relative to NH_4Cl, students decide on the dissolution of NH_4Cl **[Harmful]** as the **ONLY** suitable option.



Beaker can be insulated further with cotton wool, foil etc.

The students trial possible arrangements for the can design and determine the minimum quantity of water in which the salt can be dissolved for effective heat energy transfer from the surrounding liquid to the copper can.

Using the enthalpy of solution of NH_4Cl calculated in pre-lab Q2 part a, the students complete the theoretical calculations of;

- the heat energy transfer required to cool 100 cm^3 of drink by 5 °C
- the amount of salt which must be dissolved in the surrounding water to bring about the desired energy change

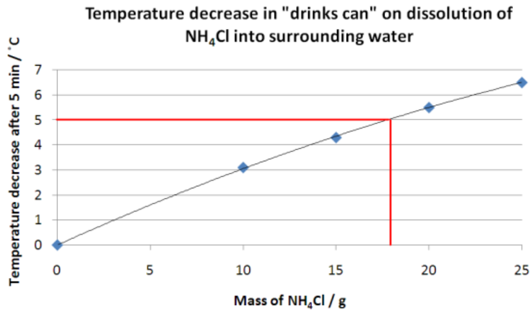
$q = mc\Delta T$ $m = (100\ cm^3 + 85\ cm^3) \times 1\ g/cm^3$

$= 3870\ J$ $c = 4.18\ J\ g^{-1}\ K^{-1}$

$= 3.9\ kJ$ $\Delta T = 5\ K$

$\therefore$ moles of NH_4Cl needed $= \dfrac{3.9\ kJ}{\Delta H_{soln}(NH_4Cl)} = \dfrac{3.9\ kJ}{17\ kJ\ mol^{-1}} = 0.23$ moles

$\therefore$ mass of NH_4Cl needed (M_r 53.5 $g\ mol^{-1}$) $= 0.23$ moles $\times 53.5\ g\ mol^{-1} = 12.3\ g$



Students trial the theoretical quantity and evaluate their method. Systematic experimentation including a calibration graph of mass of salt used *vs* ΔT will allow the students to accurately determine the experimental quantity of salt needed to cool the drink by 5 °C

Final method and design tested

= *ca* 18 g NH_4Cl dissolved in *ca* 85 cm^3 of water surrounding the "drinks can"

Teacher and technician pack

Equipment list

See the **Health and safety guidance** section in the **Introduction** for more general information on risk assessments and a key to the health and safety symbols used.

Each group will need;

120 g ammonium chloride, NH_4Cl **[Harmful]**

Accurate thermometer

100 cm^3 copper calorimeter (or similar)

250 cm^3 beaker

100 cm^3 measuring cylinder

Top pan balance

Stirring rod

Spatulas

Insulation; Paper / aluminium foil / cotton wool etc.

Boss, clamp and stand

Graph paper

Stopclock

Copies of, or access to, the CLEAPSS Hazcards for ammonium chloride and ammonium nitrate

Health and safety note

Ammonium nitrate requires very careful handling (R8: Contact with combustible material may cause fire, R9: Explosive when mixed with combustible material, **Do not allow the salt to become contaminated with organic matter and do not grind it.)**

As a result, ammonium nitrate should NOT be provided to the students under any circumstances.